Sintering, microstructure and properties of WC-FeAl-B and WC-Ni3Al-B composite materials

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Chapter 1 Introduction

Cemented Carbides

Hardmetals or cemented carbides consist of sintered hard phases (generally carbides or carbonitrides) and a relatively soft and ductile binder (generally a metal or alloy of the transition metals series) are made by powder metallurgical techniques [1-3]. The combinations of two different phases with a large number of variable parameters, such as phase chemistry, size, volume fraction and distribution, lead to varying properties. Tungsten carbide-cobalt (WC-Co) composites with certain additives, for instance minor quantities of grain growth inhibiters such as TiC, HfC, TaC, and NbC, are the important class of conventional and commercial grade WC cermets. The amount of Co in WC-Co composites is usually less than 10 wt% need in cutting tools and up to 30 wt.% for wear resistant coatings, presenting WC grain size from less than 1μm to 5 μm [4].

Cemented carbides are widely used in cutting and wear applications such as cutting tools, drilling and mining equipment and components of valves designed to handle erosive slurries. This is due to their unique combination of high hardness and moderate levels of fracture toughness [5-8]. However, hardmetals with cobalt binder have some property limitations such as poor oxidation and corrosion resistance, high density and poor binder wear resistance [9-11]. The desirable mechanical properties of these materials also are significantly degraded at elevated temperature [12].

The properties of hardmetals, particularly hardness, strength and toughness, can be improved by appropriate modification of the microstructure (e.g. the WC grain size) or microchemistry (e.g. the composition of the binder). The development of hardmetals with ultra-fine grain sizes has been of great recent interest. At present, submicron and ultrafine grades of WC-Co, with a WC grain size of 0.4 - 1.0 μm and a cobalt content ranging from 3% to 15%, still govern the market for cemented carbides [13, 14]. The fine grains and high density of interfaces can lead to considerable improvements in properties over conventional coarse grained materials [15]. Going to even finer grain sizes, it has been found that nanocrystaline materials have higher values of strength, heat capacity and ductility than conventional materials, but for the case of very fine submicron grades and nanocrystaline powders, homogeneity limitations and grain growth of WC during sintering can become considerable[16, 17].

New Binders

Cobalt as the binder has excellent wetting and adhesion to tungsten carbide and exhibits reasonable mechanical properties and processing conditions. However, Co powder is toxic and has low hardness, low strength, poor wear resistance and is quite expensive [18-20].

Over the last twenty years, considerable efforts have been made towards replacing Co by stronger and harder binders such as Ni, Fe, Ni-Fe, Ni-Co, Ni-Al, Ni-Cr-Mo, Ni-Cr-Mo-Al, Fe-Co and stainless steels to improve the properties of WC based composites [21-31]. To satisfy the basic necessary requirements for ease of processing of WC based composites by liquid phase sintering, it is important that any suitable alternate metallic binder should be able to wet the carbide and must have some solubility with W and C [32]. However, it seems that to date some of WC composites based on these alternative binders are used in special applications but most of them have not been represented as a possible replacement for Co binder in WC-Co composites, mainly due to their lower toughness and lower wettability with WC.

Intermetallic Aluminides

In recent times, intermetallic compounds, particularly aluminides, have received significant attention as potential structural materials for a wide range of applications and as alternative hardmetal binders due to their superior properties [30-33]. Iron and nickel aluminides based on FeAl and Ni_3Al have attracted the greatest attention among intermetallic compounds as new potential binders in WC composites due to their special properties [33-35]. They possess high hardness and reasonable fracture toughness; a combination of properties which generally results in high wear resistance. FeAl and Ni_3Al alloys, as compared to Co, have lower toxicity, high strength at elevated temperatures, high creep resistance, and significantly higher oxidation and corrosion resistance [32-34, 36-39]. Their unique properties can overcome certain shortcomings of cobalt binder in the WC-Co composites [11, 32]. However, the main limitation to the application of iron and nickel aluminides is their poor ductility and proneness to intergranular fractures at ambient temperatures [40, 41]. The brittle nature of binary intermetallic aluminides arises from a combination of extrinsic environmental effects such as those due to heat treatment or service and intrinsic effects such as the inherent weakness of grain boundaries [32, 41, 42].

Intermetallic Matrix Composites

The area of intermetallic matrix composites is relatively new and, for the binders based on FeAl and Ni_3Al, only a limited number of studies have been done to investigate the feasibility of production of such materials [41, 43]. Production of composites by conventional pressureless liquid phase sintering requires considerable wettability and solubility of solid phase in the binder. This technique is widely used to produce WC-Co composites [44, 45]. FeAl [11, 37] and Ni_3Al [46, 47] can wet WC without significant reaction. However, in composites based on FeAl or Ni_3Al binders, the solubility of the ceramic phase in the aluminide liquids has been found to be much lower than that of WC in Co [46, 48, 49]. Consequently, to produce intermetallic matrix composites with near full density and with low binder volume fraction in the range of that for conventional WC-Co hardmetals, some pressure might be required during liquid phase sintering [44, 50]. Although good high temperature strengths have been obtained for various intermetallic matrix composites systems, major concerns remain about their low room temperature ductility and fracture toughness [51-53].

Recent studies reported that microalloying of FeAl and Ni_3Al alloys with boron leads to significant improvements in ductility and toughness [51, 54, 55]. This is believed to be related to boron induced improvements in both environmental embrittlement and intrinsic grain-boundary weakness [42, 51, 55]. Since FeAl-B and Ni_3Al-B alloys exhibits superior properties compared to Co, they could be considered as potential alternative binders to Co in WC based hardmetals. However, it seems that the effect of boron addition to FeAl or Ni_3Al based binders in WC composites has not yet been investigated.

General Aims

The principal aims of the present work were:

(a) to study the feasibility production of sub micron WC composites based on boron doped FeAl and Ni_3Al binders with near full density by uniaxial hot pressing process.

(b) to investigate of the effect of boron on the compatibility between WC and aluminide binders, microstructure and mechanical properties.

(c) finally, comparison of the intermetallic matrix composite properties to those of WC-Co fabricated using similar uniaxial hot pressing technique, and commercial grade of WC-Co composite.